
Coherent Transition and Smith-Purcell Radiation Experiments on the HRC MIT 17 GHz Linac

Roark A. Marsh, Amit S. Kesar, Richard J. Temkin

Massachusetts Institute of Technology,
Plasma Science and Fusion Center,
Cambridge, Massachusetts 02139, USA

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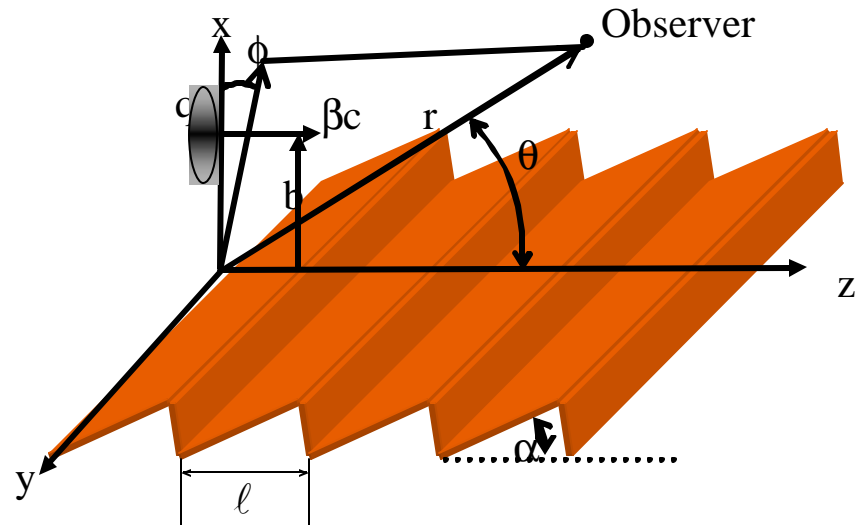
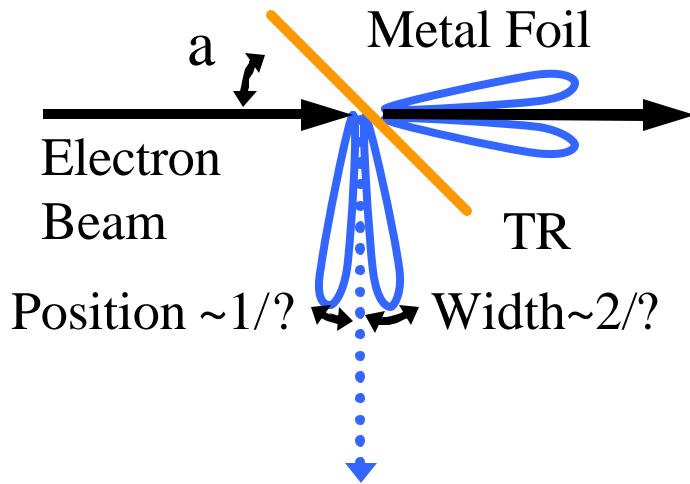
Outline

- ❑ Motivation
- ❑ Introduction
- ❑ Experimental Setup
- ❑ Experimental Results
- ❑ Conclusions, Future Work

Motivation

- ❑ Understand Radiation
 - Measure Frequency Content
 - Measure Absolute power, confirm with theory
- ❑ Use this information for bunch length diagnostics
- ❑ SPR
 - Measure bunch length by looking at coherence cutoff, overall shape of radiation
 - Measure bunch length by looking at absolute power
- ❑ CTR
 - Measure bunch length by looking at coherence cutoff, absence of higher frequency-locked harmonics

TR and SPR



- ❑ Transition Radiation from an infinite foil
- ❑ Broad Frequency content

- ❑ Angular position related to observation frequency

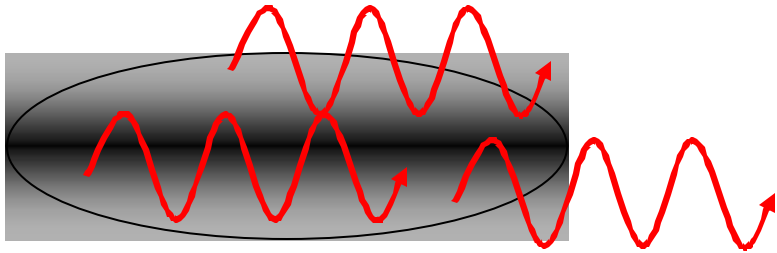
Resonance condition:

$$n\ell = \ell \left(\frac{1}{b} - \cos q \right)$$

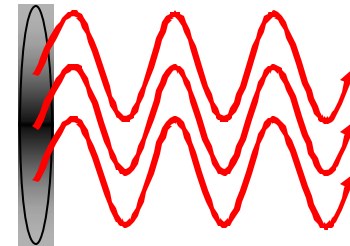
Coherent TR and SPR

- ❑ Radiation from Electron bunches $N_e \sim 10^8$

Incoherent



Coherent

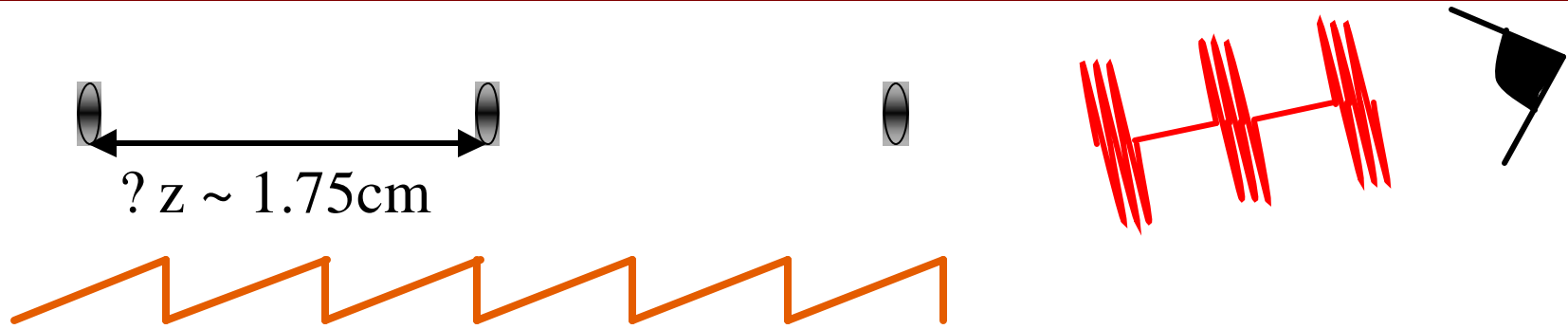


- ❑ Coherence Condition
 - $P \propto N_e$ for $s < \text{bunch length}$
 - $P \propto N_e^2$ for $s > \text{bunch length}$

$$N_e S_{\text{inc}} + N_e^2 S_{\text{coh}}(I)$$

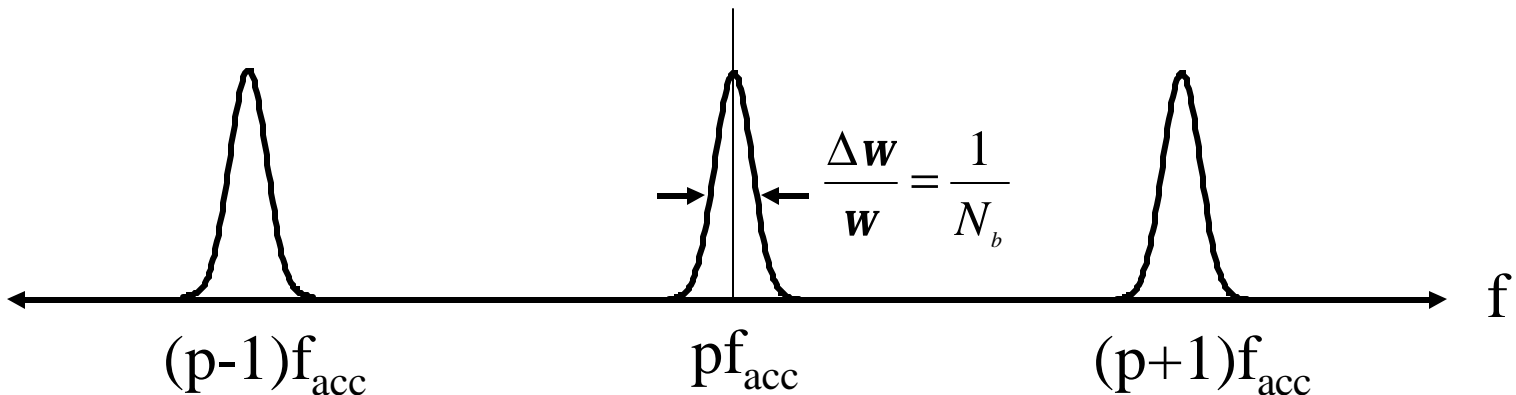
- ❑ Gaussian Bunch: $S_{\text{coh}} \propto e^{-\left(\frac{2ps}{l}\right)^2}$ for $s > \text{bunch length}$

Radiation from a Train of Bunches



$$J_{Total}(\mathbf{w}) = \sum_m^{N_b} J_1(\mathbf{w}) e^{imk\Delta z} = J_1(\mathbf{w}) \sum_m^{N_b} e^{i2\mathbf{p}m \frac{f_{sp}}{f_{rf}}}$$

$$\text{Intensity} \propto \left[\frac{\sin(\mathbf{p}N_b f_{sp}/f_{rf})}{\sin(\mathbf{p} f_{sp}/f_{rf})} \right]^2 \xrightarrow{N_b \rightarrow \infty} \mathbf{d}(f_{sp} - \mathbf{p}f_{rf})$$



Electric Field Integral Equation

- ❑ We need a way to analyze Radiation
 - Analytic calculations for transition radiation
 - Model needed for SPR

- ❑ From Maxwell's equations
 - Integral Formulation: Grating
 - Frequency Domain: Frequency content, not time evolution
 - Green's function: three dimensional charge distribution

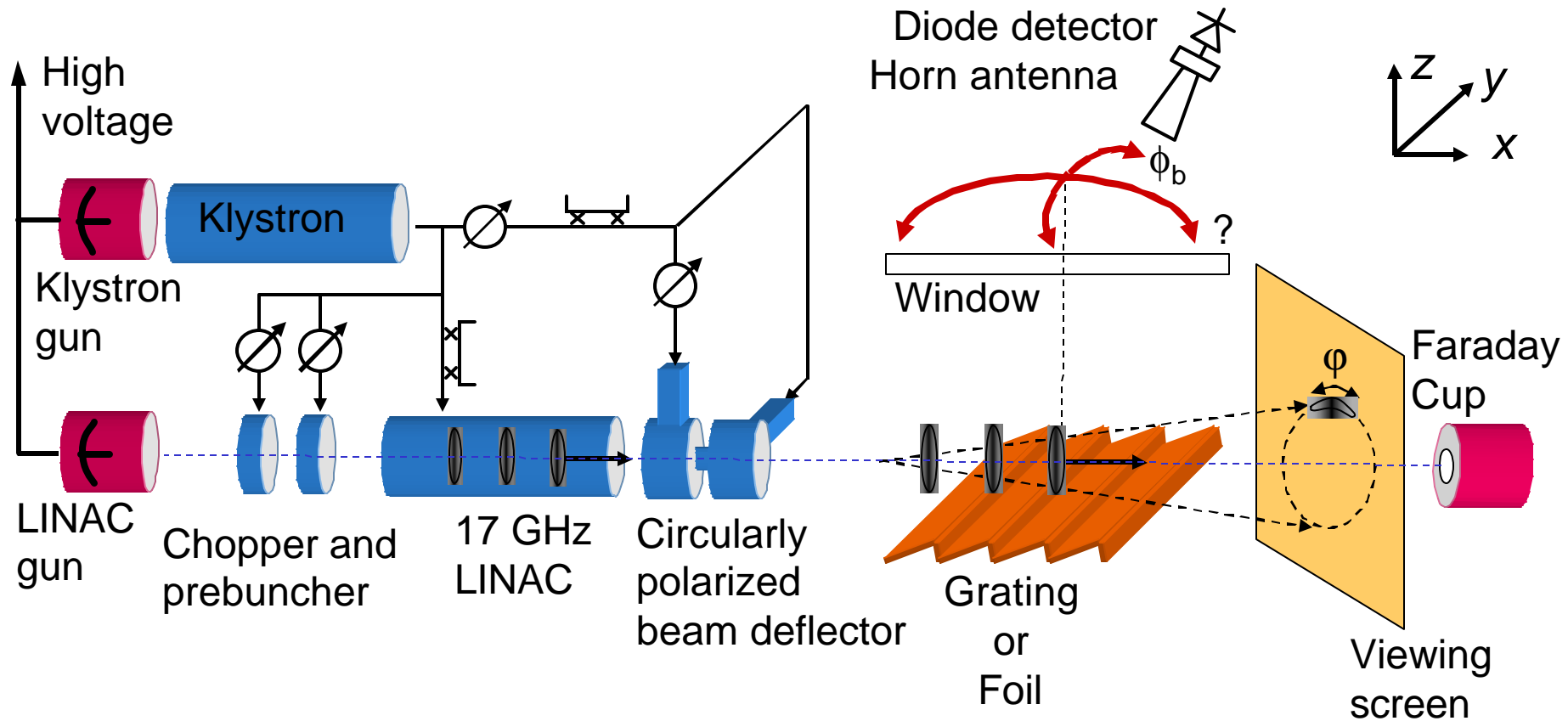
$$\tilde{\mathbf{A}}(\mathbf{r}, k_x, \omega) = \frac{m_0}{4p} \int_{\text{Grating surface}} dc' \tilde{\mathbf{J}}(\mathbf{r}', k_x, \omega) G(k_x, \mathbf{r} - \mathbf{r}')$$

$$j\omega m_0 \tilde{\mathbf{E}}^{ref} = \nabla \nabla \cdot \tilde{\mathbf{A}} + k^2 \tilde{\mathbf{A}}$$

$$\tilde{\mathbf{E}}_{\parallel}^{inc} = -\tilde{\mathbf{E}}_{\parallel}^{ref} \text{ (on surface)}$$

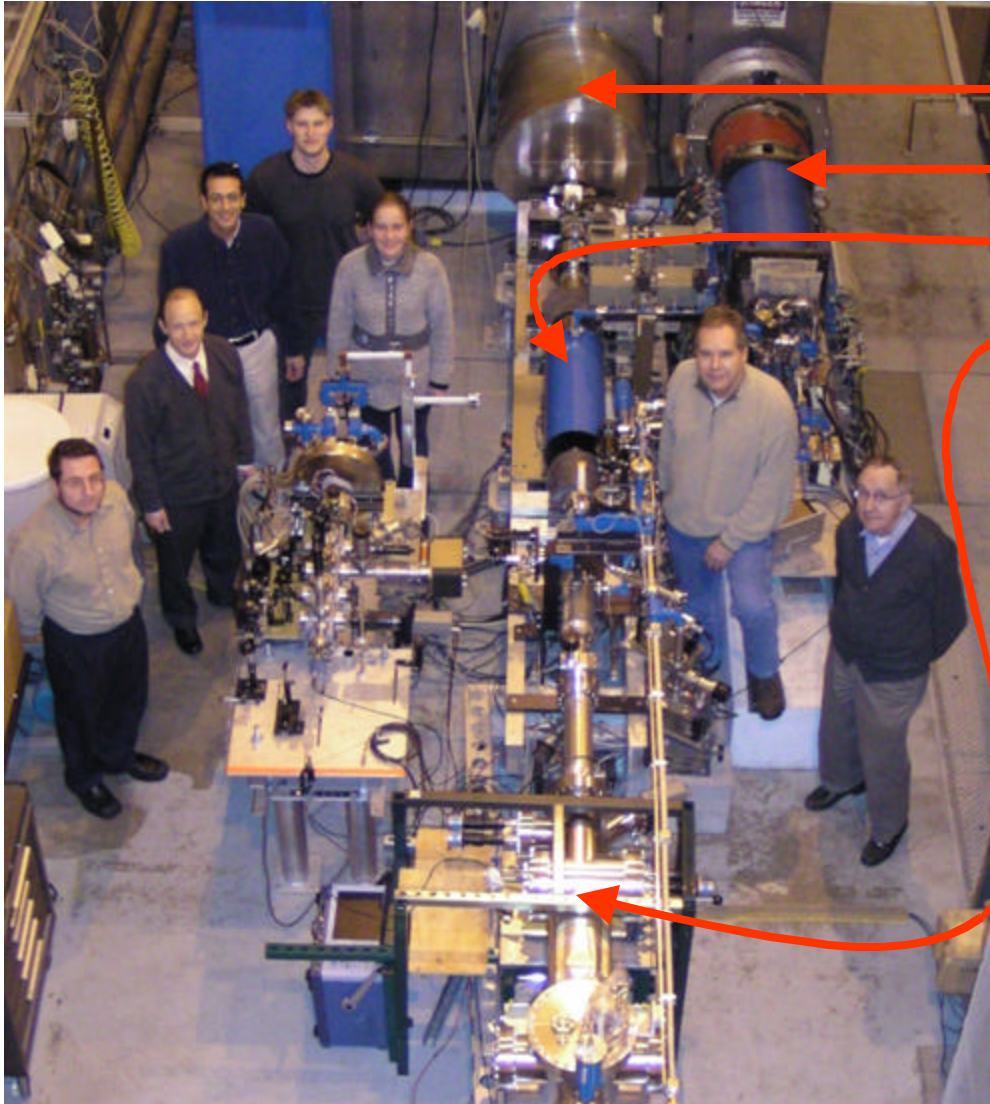
\mathbf{A} vector potential
 \mathbf{J} surface current
 G green's function
 \mathbf{E} electric field

Experimental Setup



□ HRC bunch length diagnostic to confirm measurements

Accelerator Lab



DC Gun

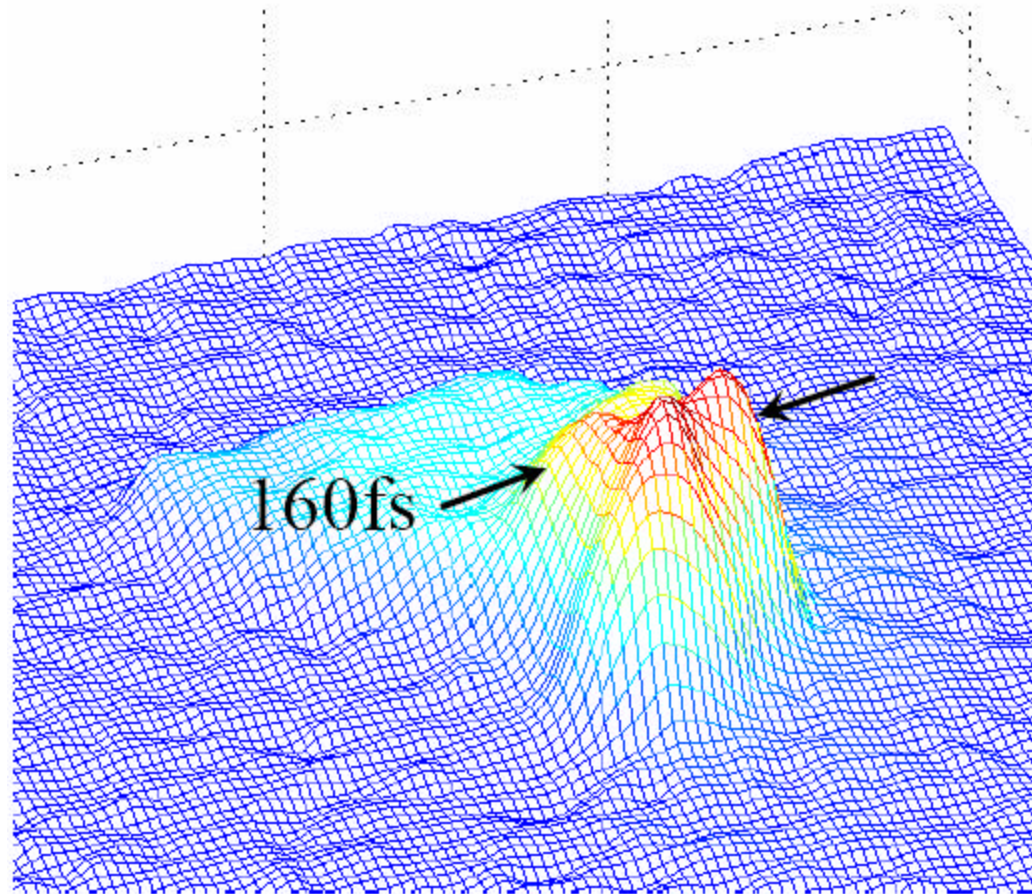
17.14 GHz Klystron

0.5m Linac

CTR/SPR Experiments

Parameter	Value
Frequency	17.14 GHz
Beam Energy	15-20 MeV
Average Current	~100 mA
Charge/Bunch	6 pC
Train Length	40-100 ns
Bunch Length	.1-1 ps

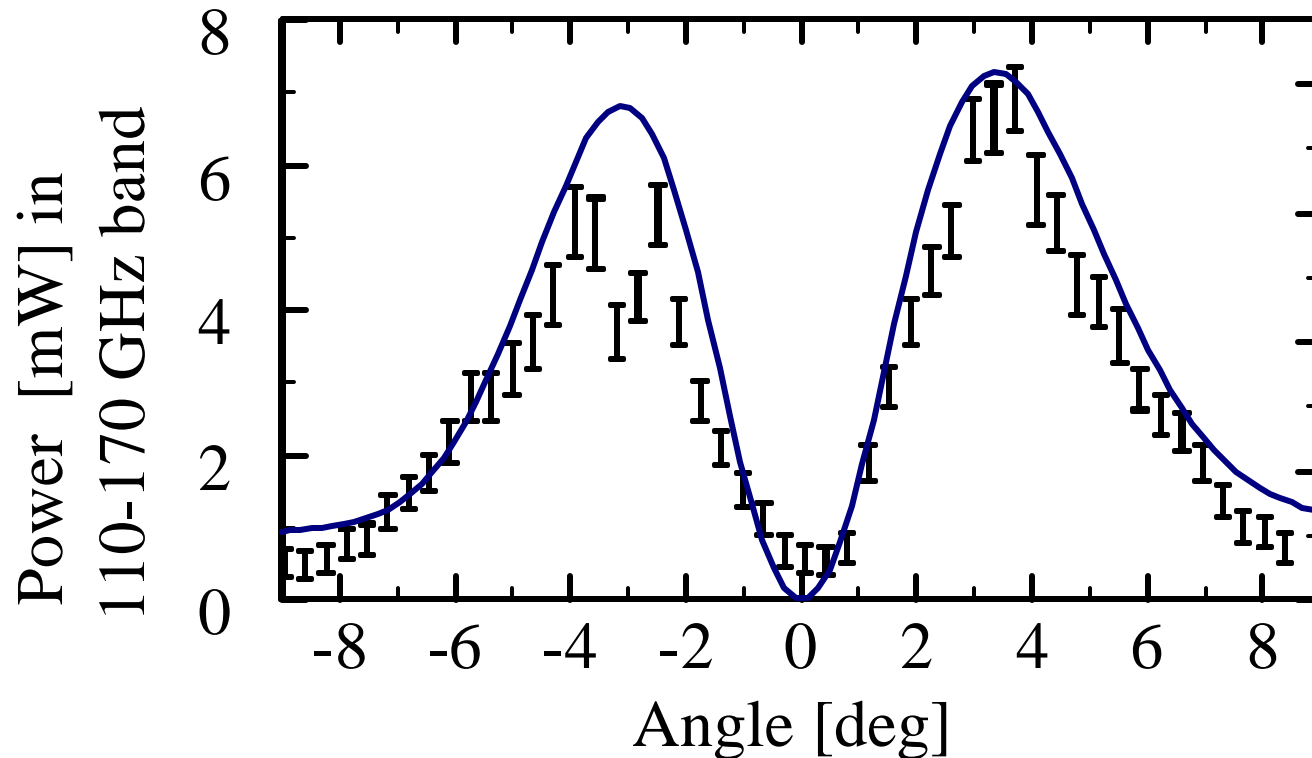
HRC Circularly Polarized Deflector



Haimson,
AAC02
AAC04

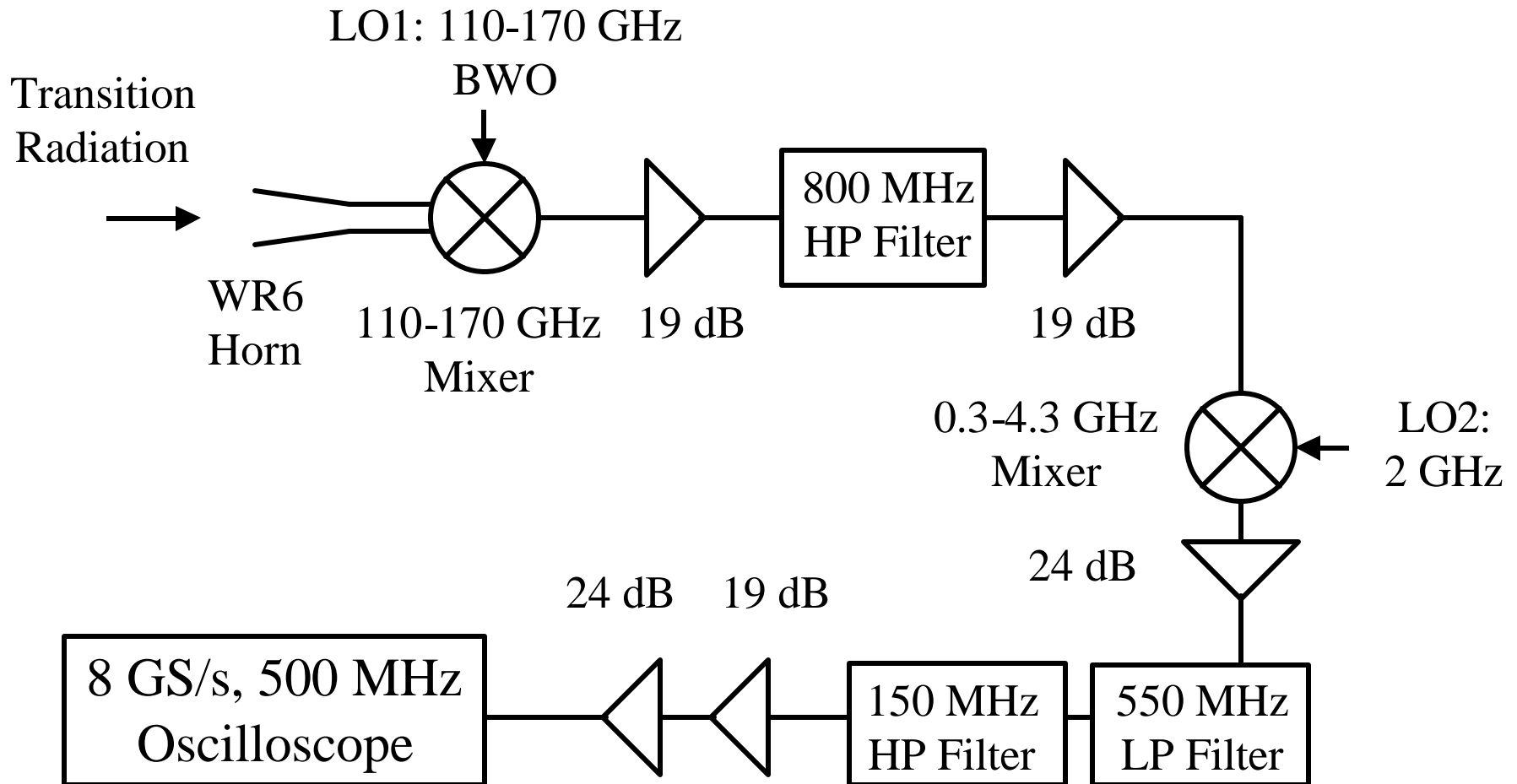
- ❑ This destructive technique is in use at MIT to confirm our other bunch length measurements

CTR Angular Power Distribution



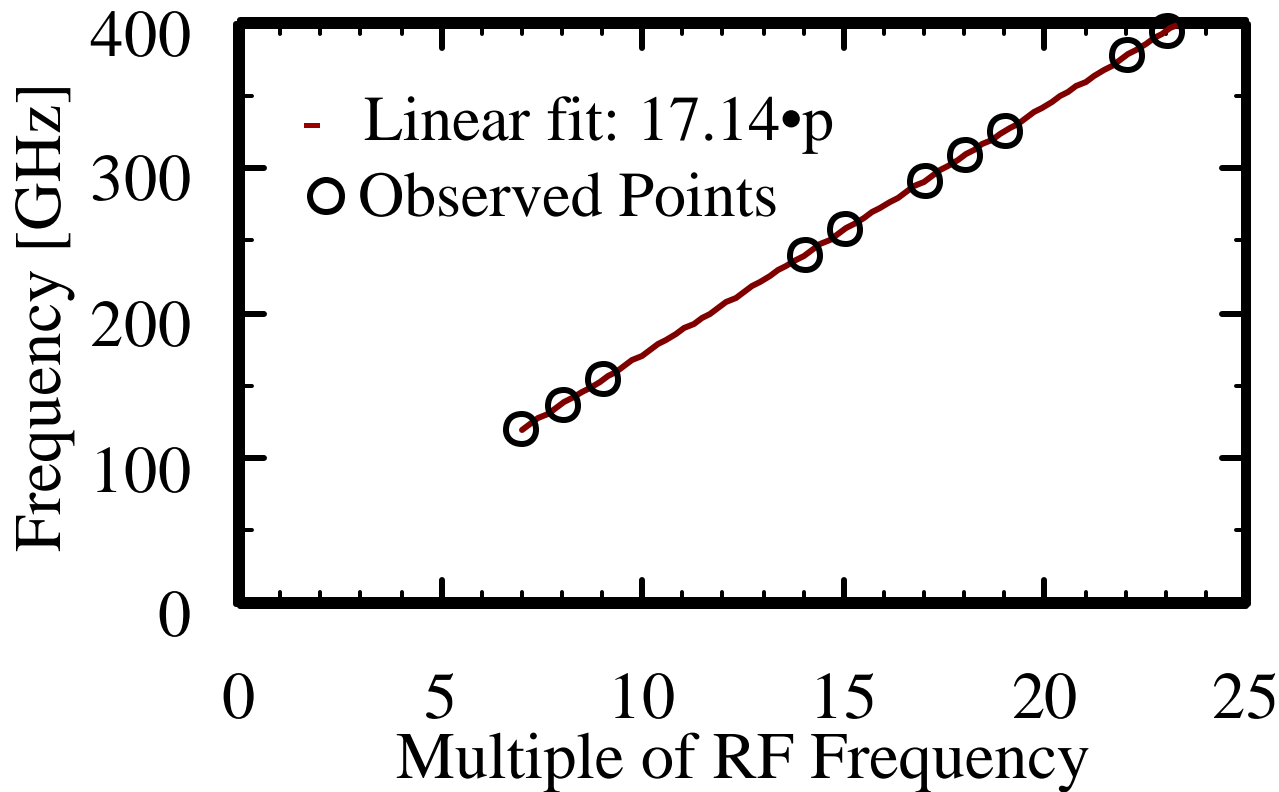
- ❑ EFIE code results and WR6 Diode measurements
 - Power calculated in 110-170 GHz band
- ❑ Results compared on Absolute scale

Double Heterodyne System



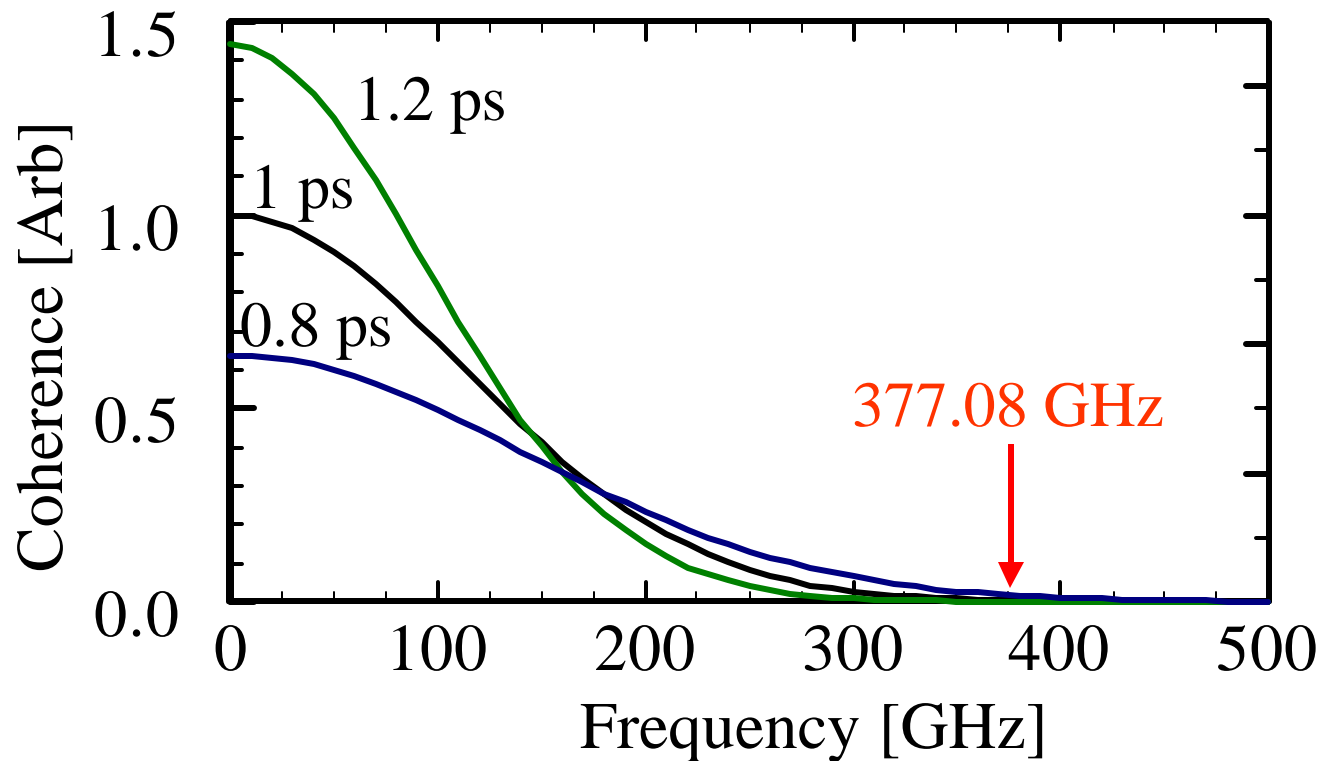
$$f_{CTR} = mf_{LO1} \pm \Delta \pm f_{LO2}$$

CTR Heterodyne Measurements



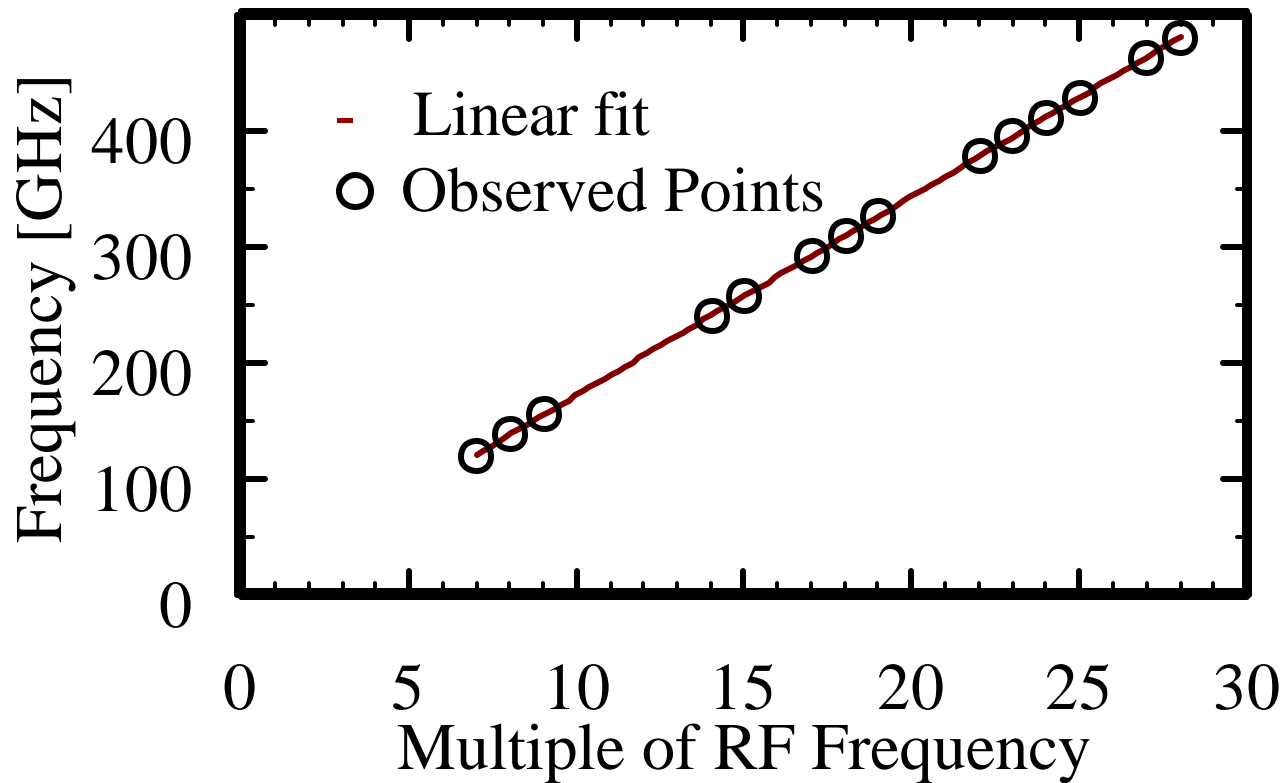
□ Due to frequency-locking, instead of observing a continuous range of frequencies, we observed only discrete frequencies $f = p f_{\text{RF}}$ for integer p

CTR Bunchlength diagnostic



- ❑ Maximum frequency observed is 377.08 GHz
- ❑ This corresponds to an estimated BL of 1 ± 0.2 ps
- ❑ Limiting error is from $f_{RF} = 17.14$ GHz, 50fs

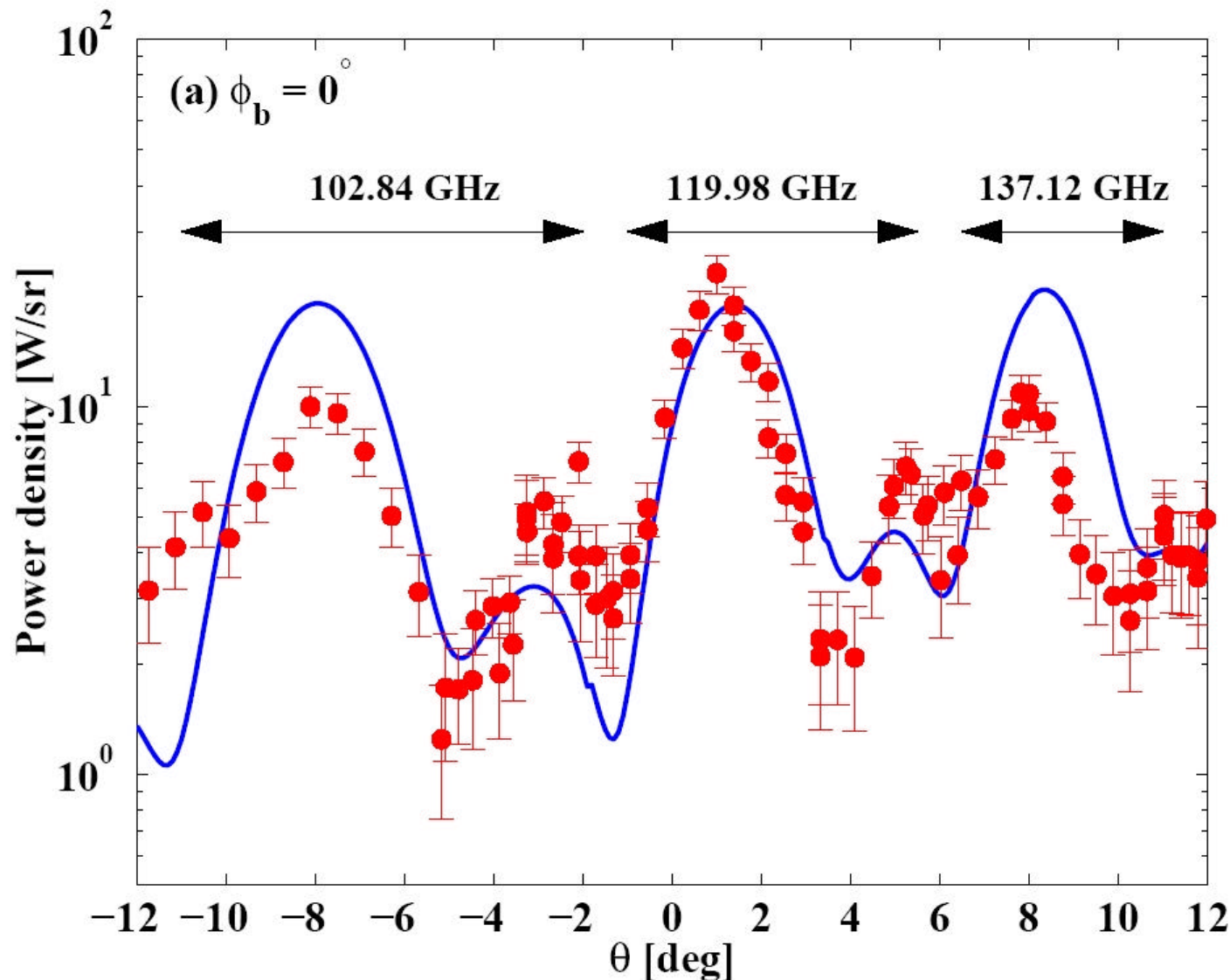
SPR Heterodyne Measurements



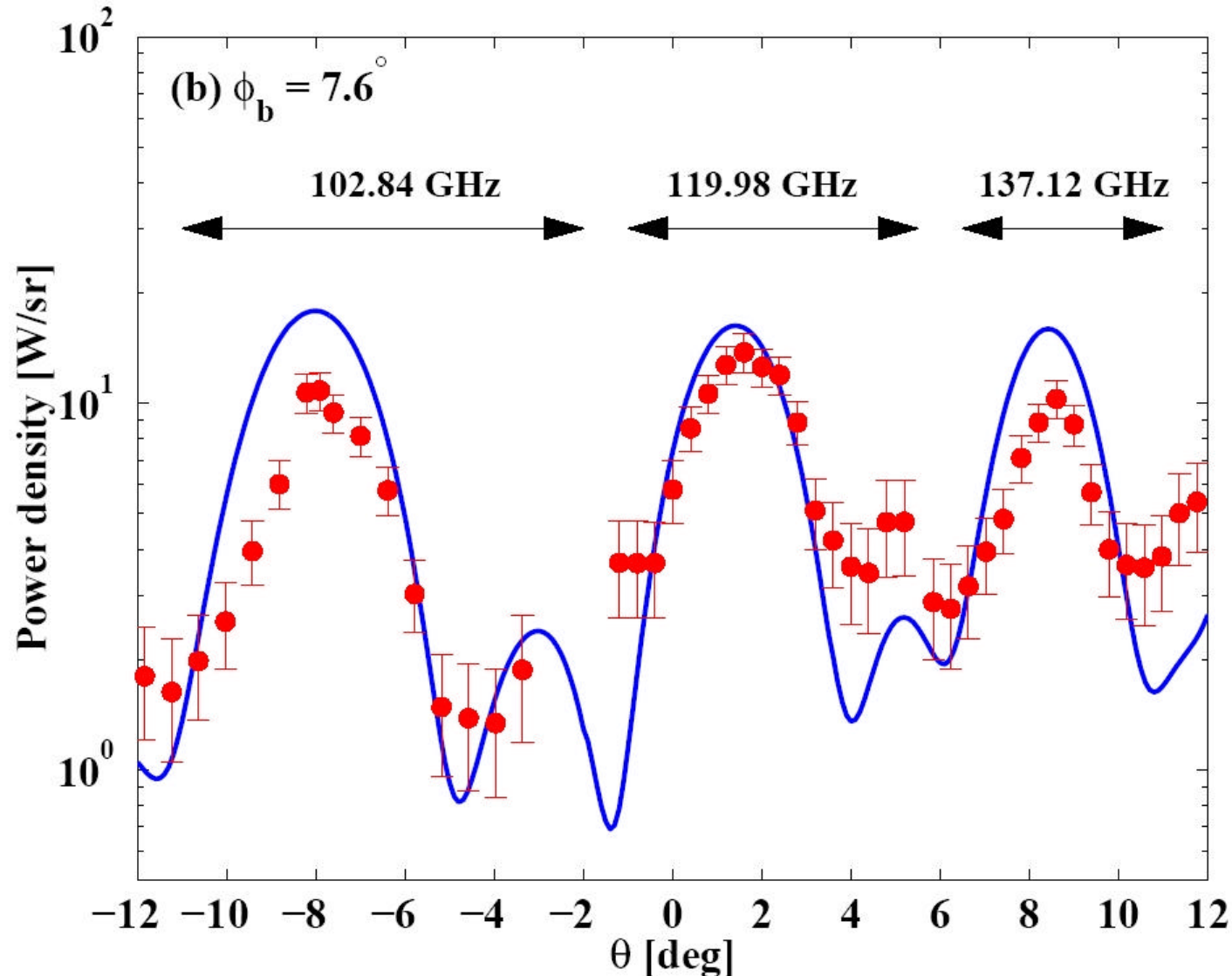
❑ Only discrete frequencies $f = p f_{\text{RF}}$ are observed

❑ Multiples up to 479.92 GHz

SPR Angular Power Distribution

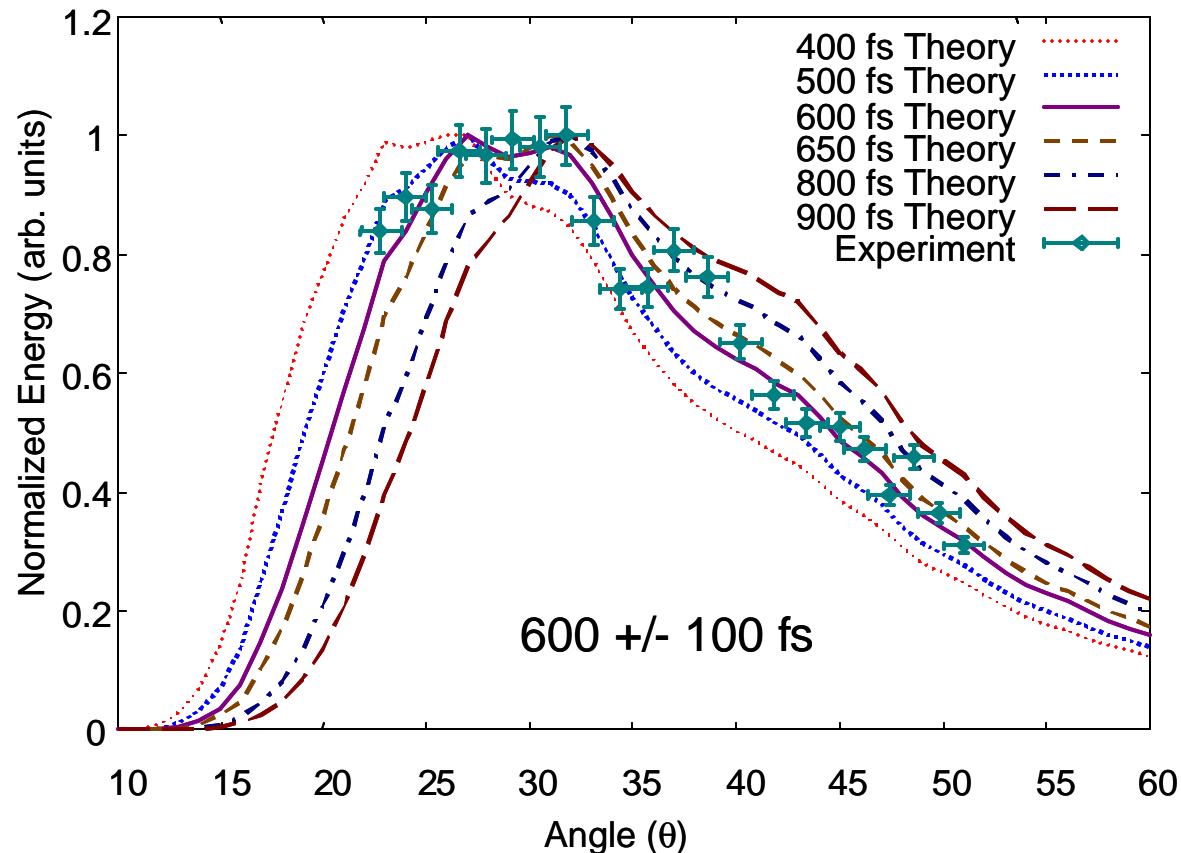


SPR Angular Power Distribution



Relative SPR BL Measurement

- ❑ Coherence cutoff correlates with bunch length



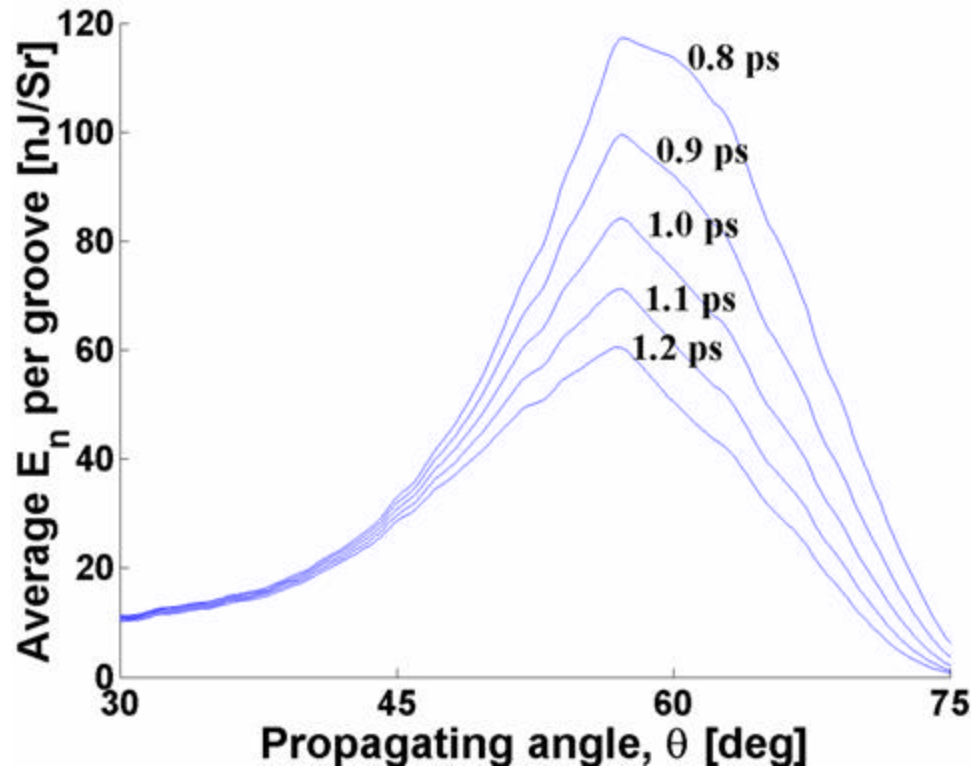
- ❑ Bolometer Measurements

Korbly, PRL (2005)

PRSTAB (2006)

Absolute SPR BL Measurements

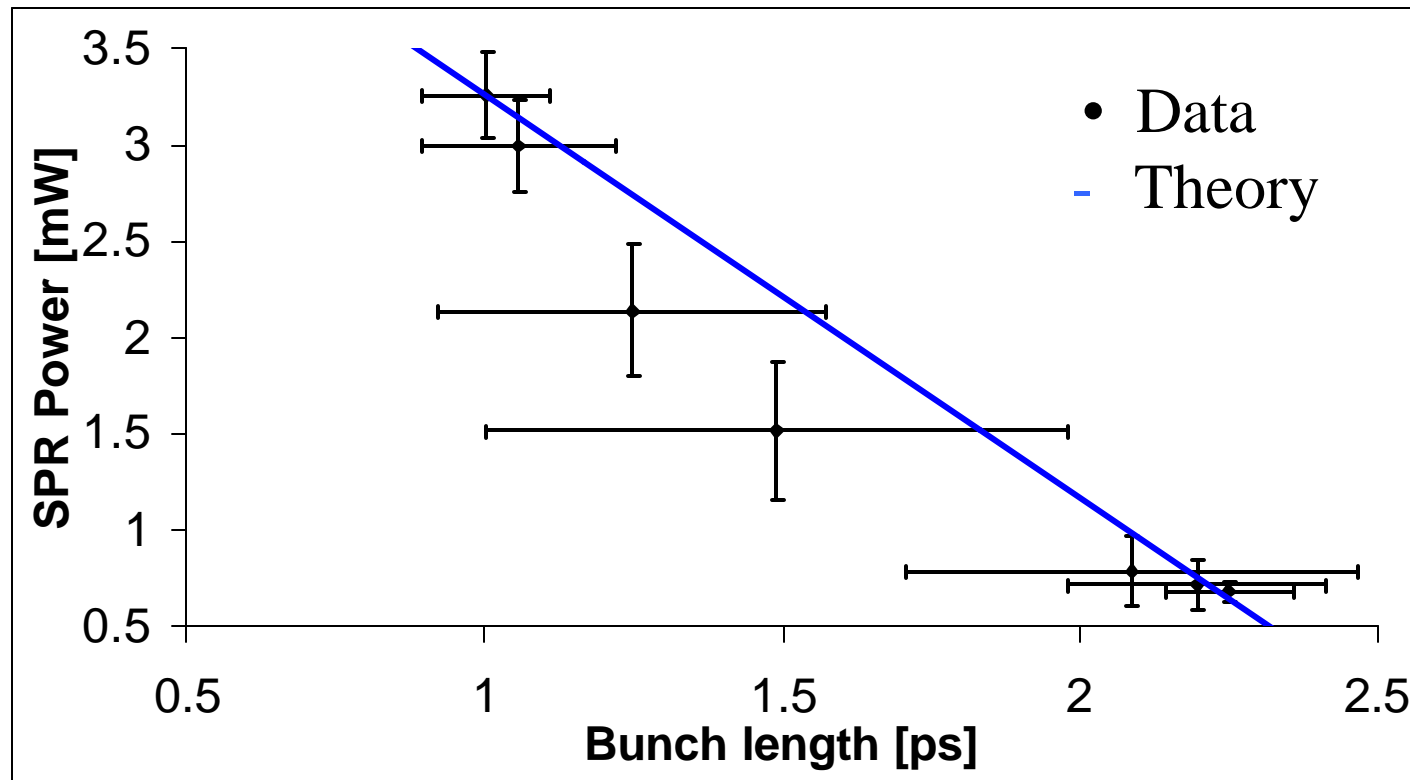
- ❑ EFIE code results show predicted absolute power as a function of Bunch Length



- ❑ If absolute power measurements can be made then the bunch length can be determined

Preliminary Absolute BL Data

- ❑ Accelerator run with very long pulses
- ❑ Using existing grating as proof of principle



- ❑ Next step is to design a grating for shorter bunches

Conclusions and Future Work

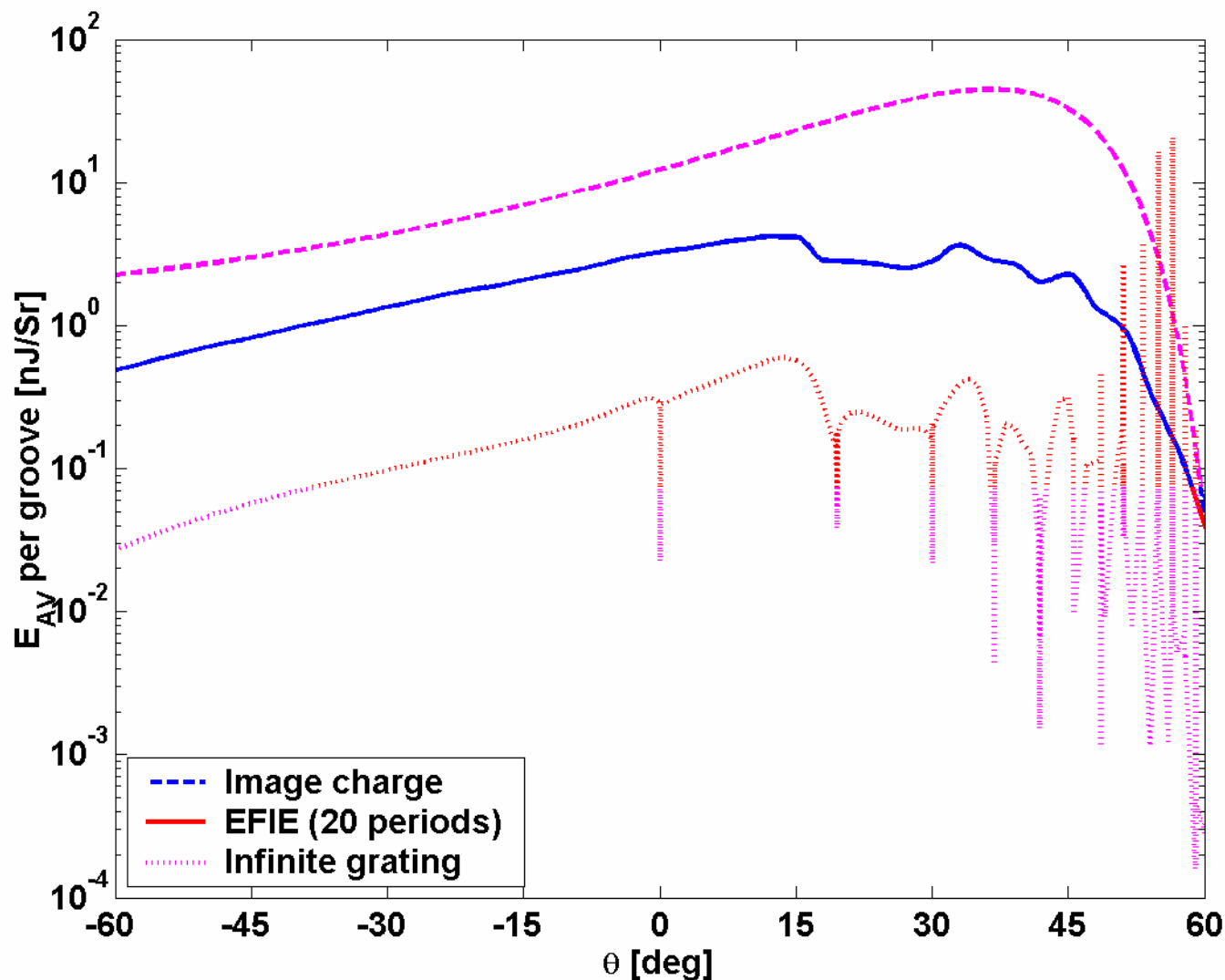
- ❑ Measured absolute power of radiation
 - Coherent Transition Radiation
 - Smith Purcell Radiation
 - Results agree with EFIE code

- ❑ Diagnostic
 - Bunch length from relative SPR measurements
 - Bunch length from frequency-locking of CTR
 - Measurements agree with destructive HRC diagnostic

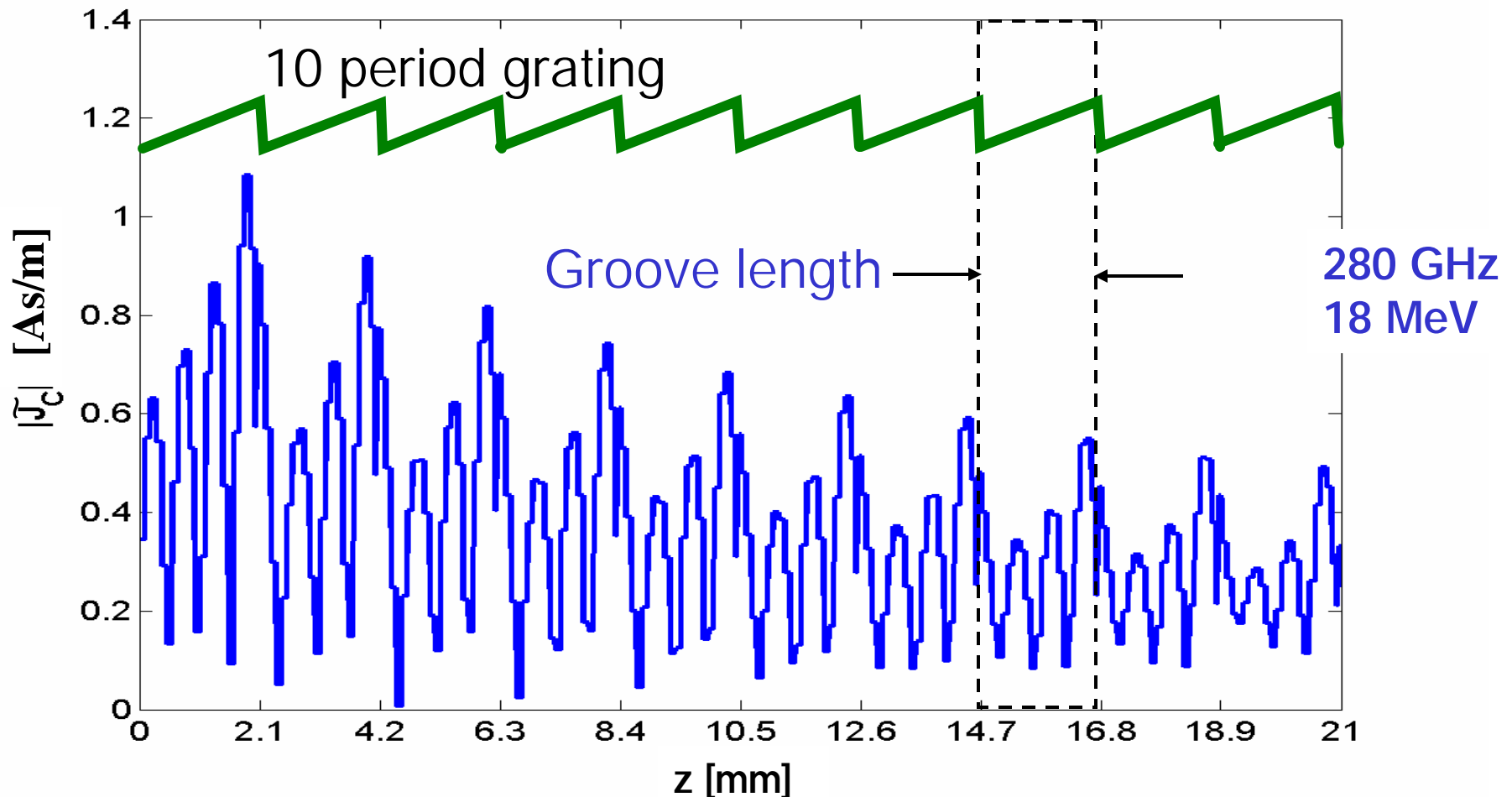
- ❑ Absolute Power Diagnostic
 - SPR
 - Preliminary work done with long bunches
 - Designing grating for shorter bunches



Comparison of SPR Energy

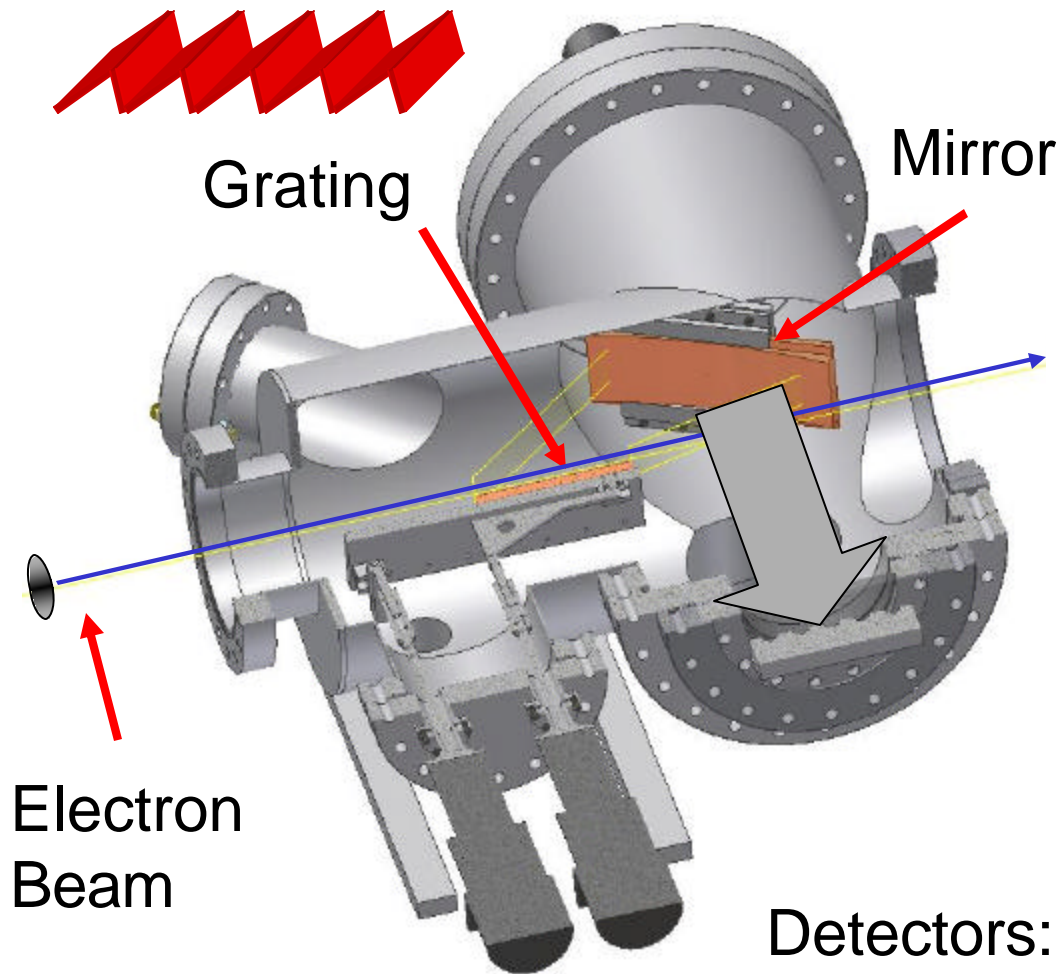


Finite Length EFIE



Finite grating effect is seen in the surface current envelope

SMITH-PURCELL EXPERIMENT



Parameter	Value
Beam Energy	15 MeV
Electrons/ Bunch	$6 \times 10^7 (9 \text{ pC})$
Emittance	$2.5\pi \text{ mm-mrad}$
Beam height	0.75 mm
Grating Period	2.1, 6, 10 mm
Blaze Angle	10°

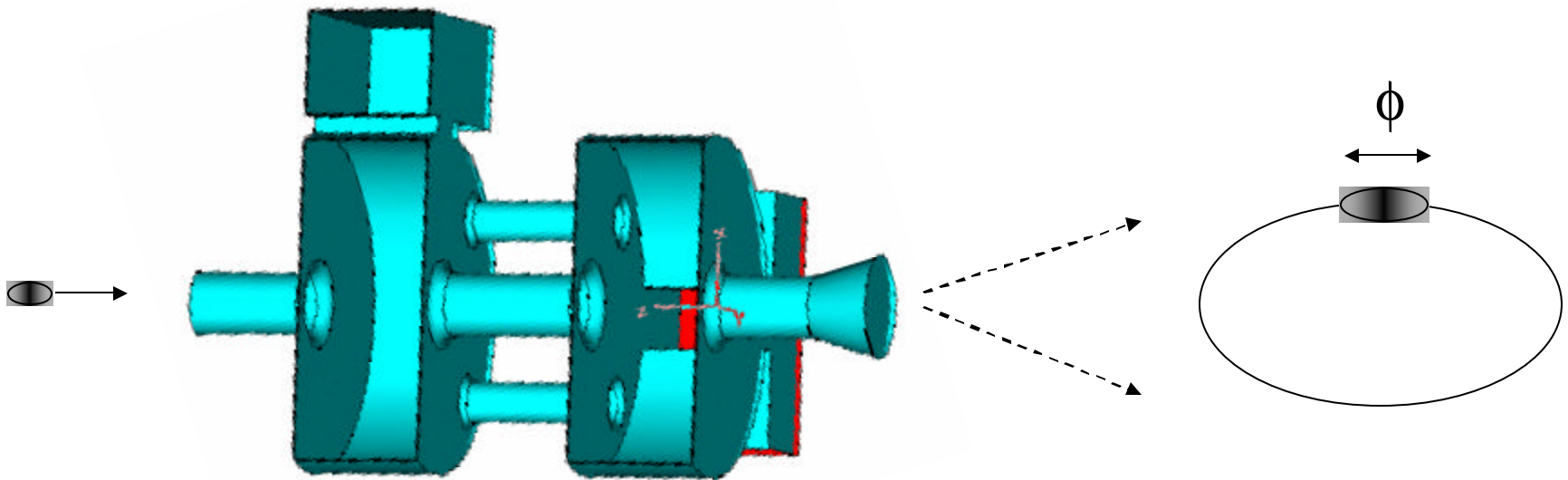
Detectors:

Bolometer (thermal detector – absorbs photons)
Heterodyne Receiver (coherent detector)

HRC Circularly Polarized Deflector

Beam Deflecting Cavity

TM_{11} Mode

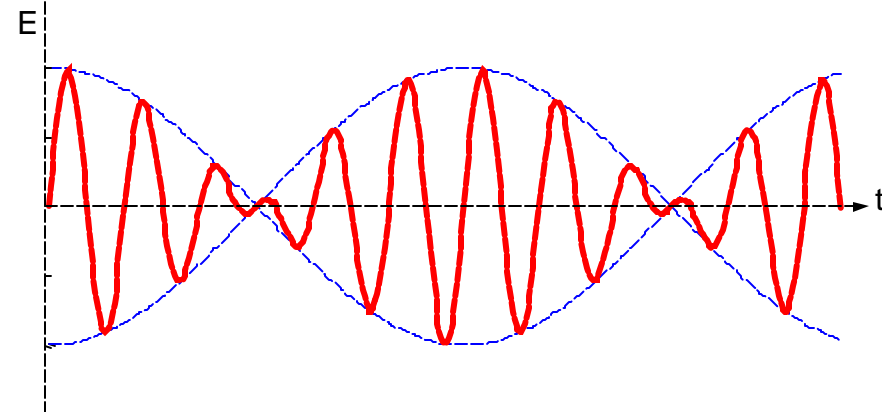
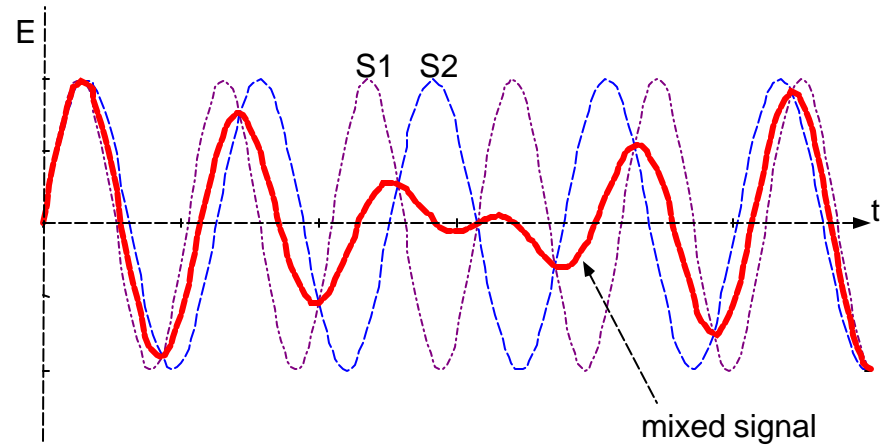
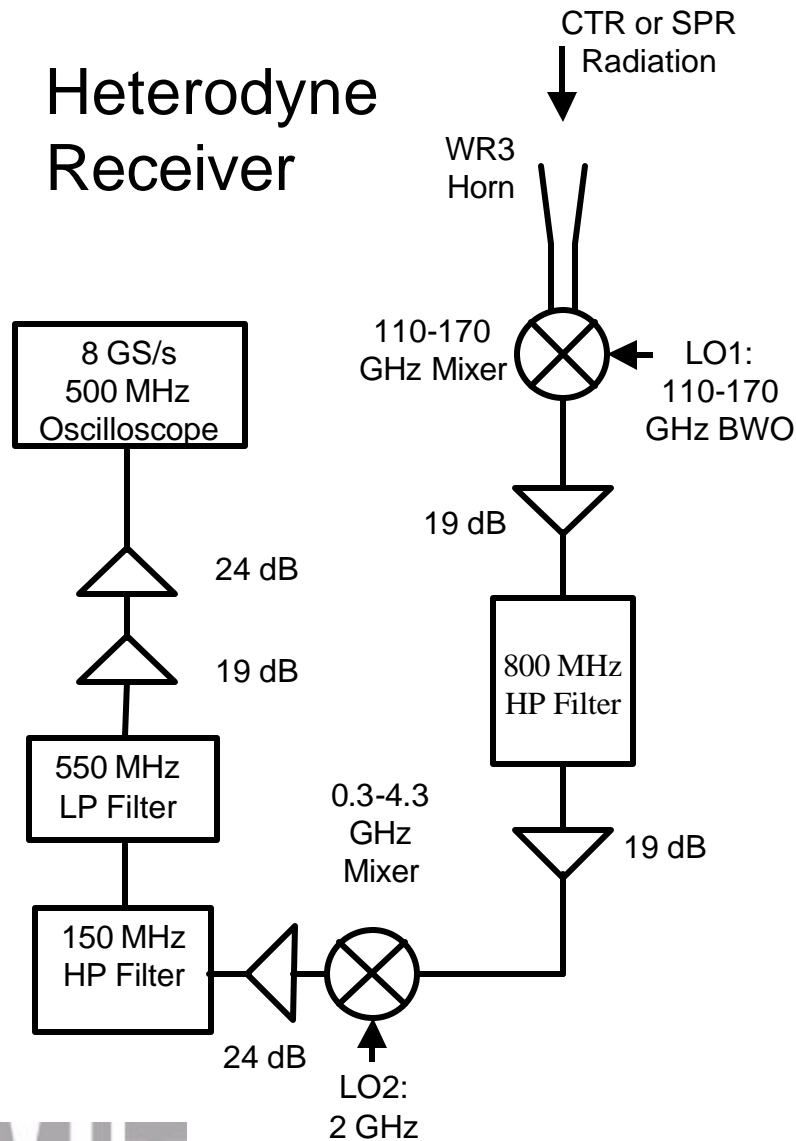


- ❑ This technique in use at MIT
 - Measurements used to confirm SPR BL

Haimson, AAC02

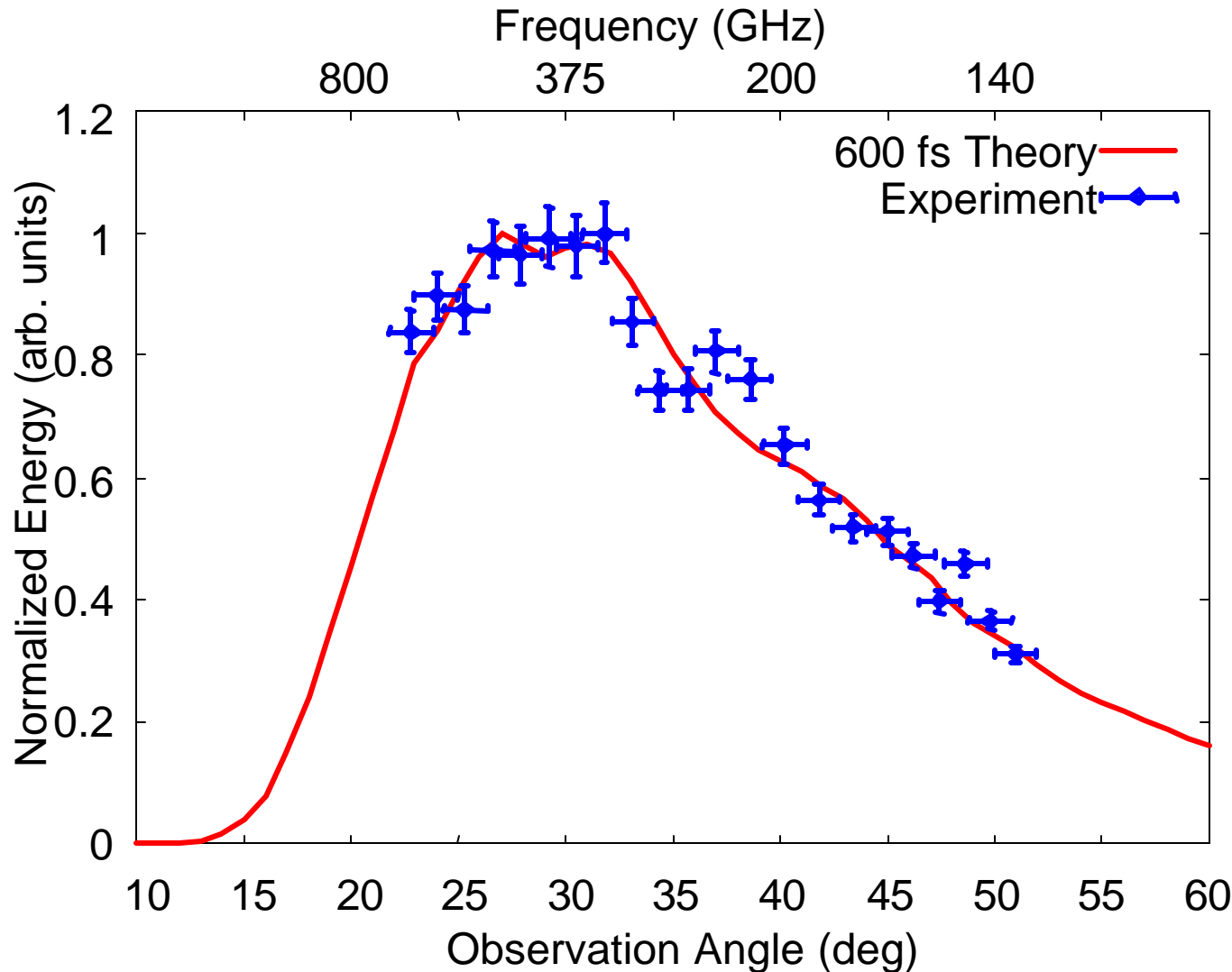
Frequency Measurements

Heterodyne Receiver



$$f_{sp} = nf_{LO1} \pm f_{LO2} \pm \Delta$$

S-P ENERGY VS. ANGLE



Short Pulse
Operation

$E = 15.5$ MeV
 $\ell = 6$ mm
 $b = 0.75$ mm
 $P_{PB} = 1.2$ kW
 $P_{CH} = 1.1$ kW